WHY HIGH SPECTRAL RESOLUTION IS NEEDED FOR THE CONSTELLATION-X MISSION

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Collaborators

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Chris Reynolds	University of Maryland

Outline of the talk

- How useful is high resolution spectroscopy?
- What is the structure in the IGM?
- Characterizing warm absorber gas in AGN spectra
- Dynamics of stellar coronae
- What spectral resolution is needed for Con-X?

1 How useful is high resolution spectroscopy?

An important lesson learned from UV spectroscopy of plasmas with emission line spectra (temperatures from 10^3 to 10^7 K) is that high spectral resolution spectra is required to infer the information contained in the spectral lines:

- Separate line blends
- Correct for line saturation
- Determine line shapes and Doppler shifts
- Measure abundances accurately, etc.

Two examples:

(1) α **TrA observed with STIS E230H:** Separately measure the emission line strength, two interstellar absorption lines, and the shape of the wind absorption. (See Figure 1.)

(2) AD Leo observed with STIS E140M: Separate the Fe XXI 1354.08 Å line from the C I 1354.288 Å line ($\Delta v =$ 46 km/s), measure the Fe XXI line width and Doppler shift. (See Figure 2.)

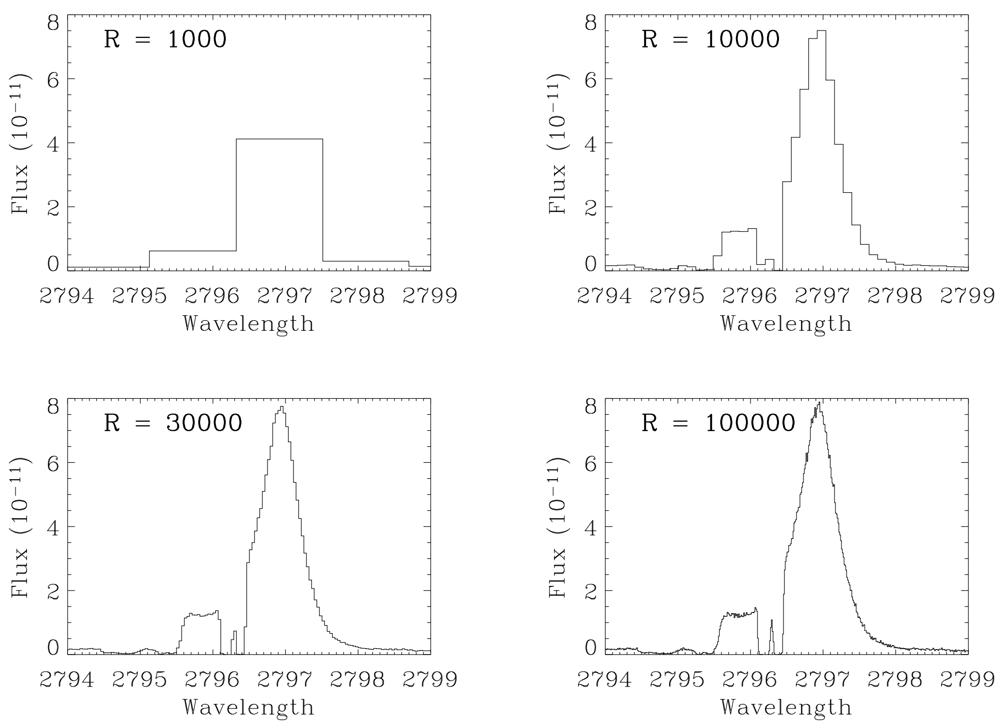


Figure 1: Spectrum of the Mg II λ2796 Å line of the K4 II star α TrA obtained with the high resolution echelle mode of HST/STIS. The resolution is R = $\lambda/\Delta\lambda$ = $100,000$ (3 km s^{-1}). The chromospheric emission line is altered by two narrow interstellar absorption lines near 2796.5 Å and a complex wind absorption feature on the blue side of the chromospheric emission line. As the resolution is degraded, the information content of the line profile disappears.

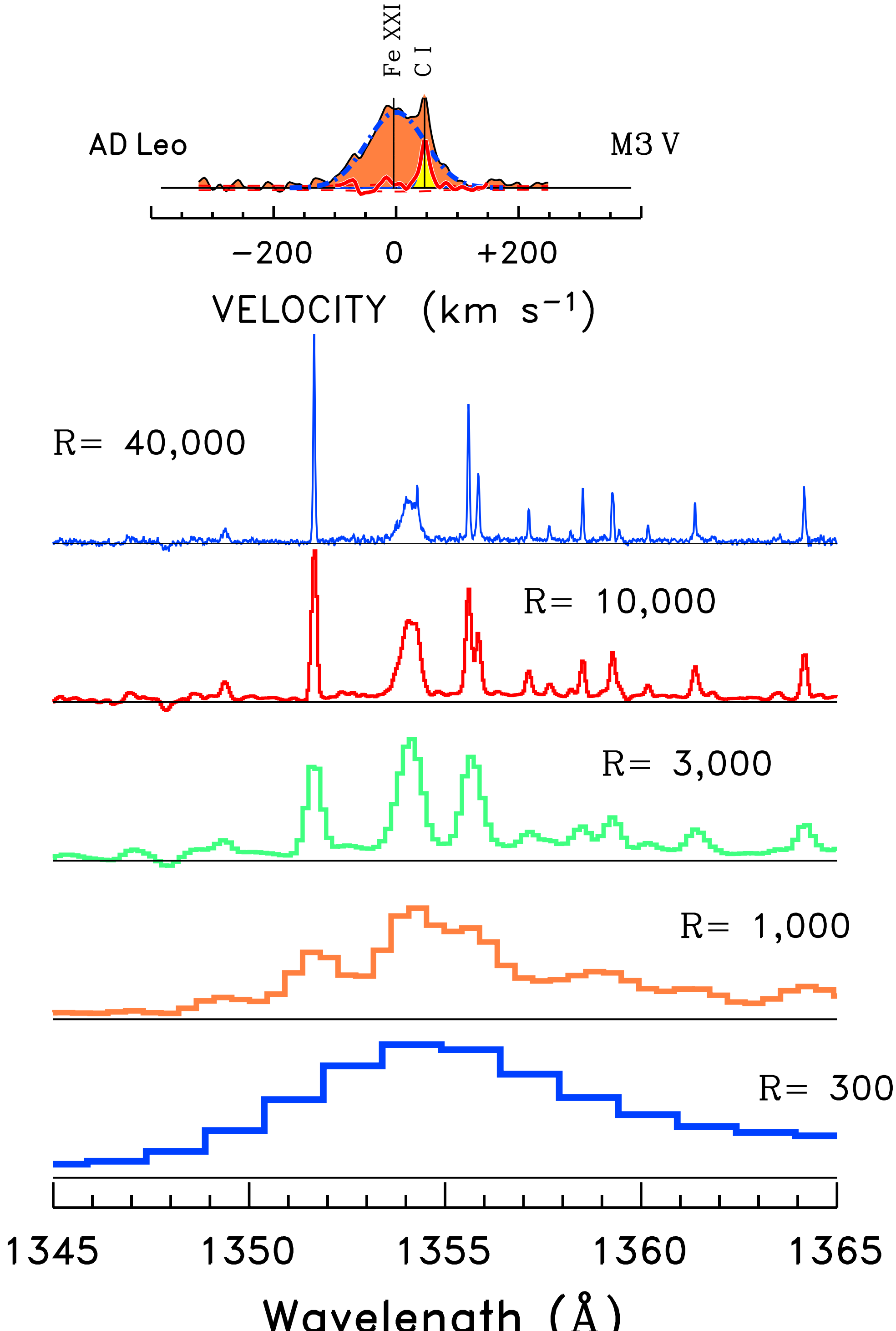


Figure 2: The high resolution HST/STIS echelle spectrum of the M dwarf flare star AD Leo. The Fe XXI line can be separated from the C I blending line at R = 40,000 and perhaps at R = 10,000, but not at lower resolution. At R = 1,000 it is not even clear that the Fe XXI line is present in the spectrum.

What resolution is needed to characterize the IGM (absorption line fluxes, components, and line widths)?

- Simulation for the O VIII Lyman-α line at 20.02 Å in the direction of PKS 2155-304. (see Figure 3).
- Continuum flux 0.0033 ph/cm^2/s/Å (Fang et al 2002, ApJ 572, L127).
- Simulation by Nick Gnedin assuming $A_{eff} = 3,000$ cm^2 and an integration time of 50 ks.
- Since the line is saturated, need R = 3,000 to measure the line column density.
- To measure the line width need R = 3,000.

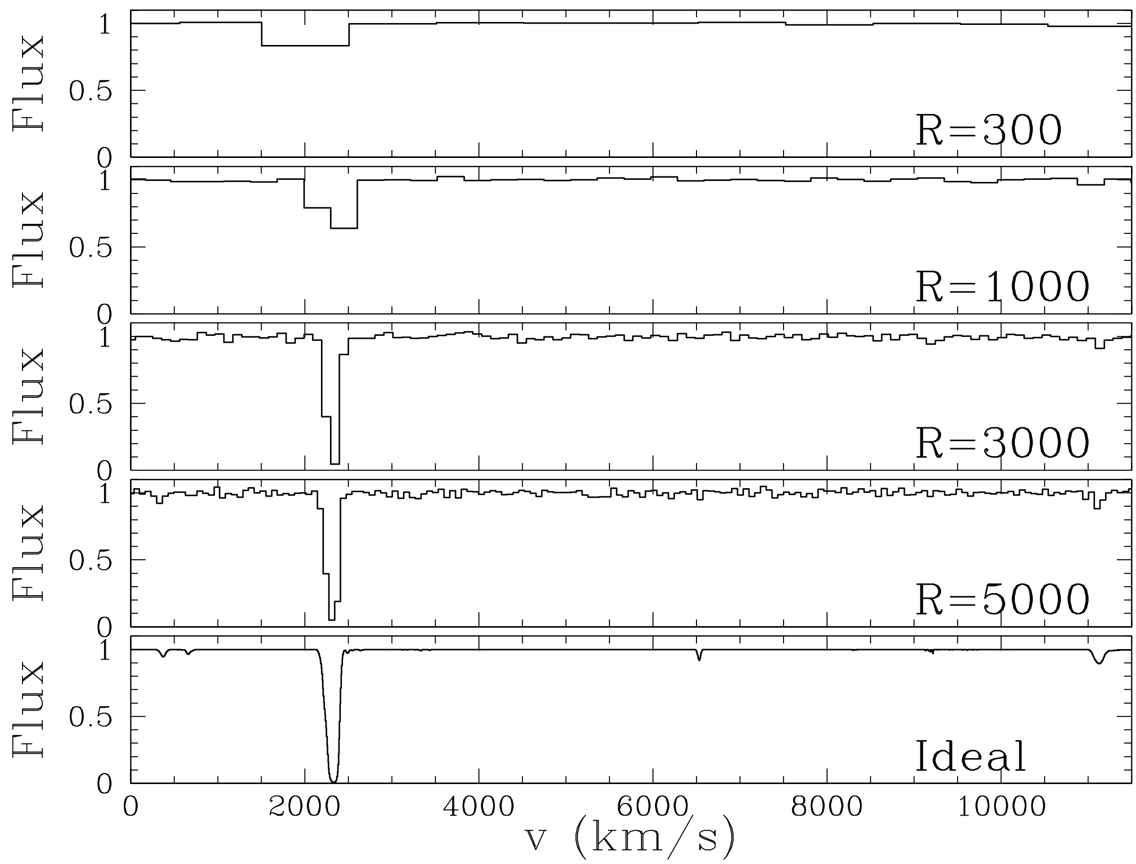


Figure 3: Simulation for the O VIII Lyman-α line at 20.02 Å in the direction of PKS 2155-304. Line saturation is evident for resolutions greater than 3,000. At lower resolution one would likely conclude that the line is optically thin.

Simulated spectrum of an AGN continuum and "warm absorber" gas computed by Chris Reynolds.

- Assume $A_{eff} = 3,000$ cm^2 and an integration time $t = 10^5$ seconds.
- Power law AGN continuum with a photon index of 2.
- Absorption by a large column density ($N_H = 10^{23}$ cm^{-2}) of highly ionized gas.
- Ionization parameter $L/nr^2 = 1,000$.
- We compute a rich absorption line spectrum that can be studied in high resolution data. (see Figures 4 and 5).

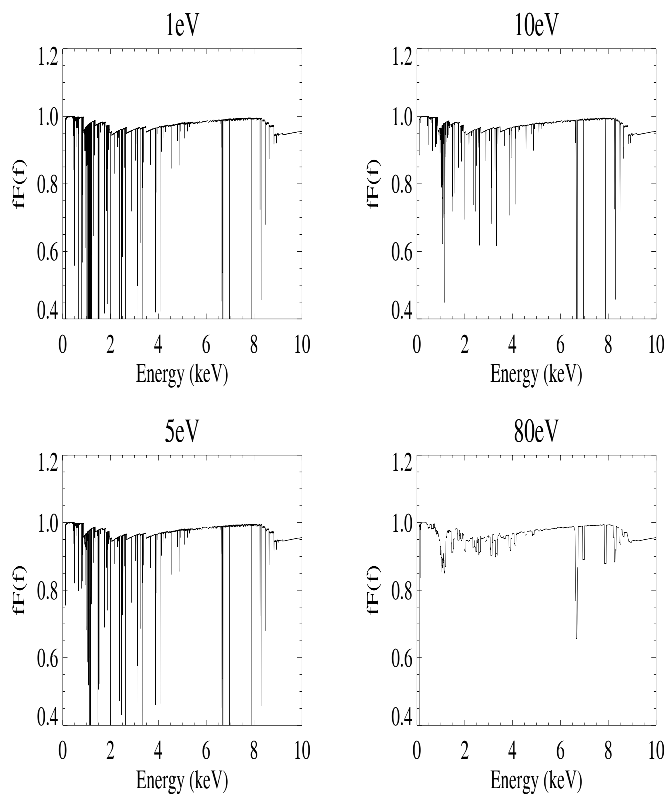


Figure 4: Simulated spectrum of an AGN continuum and "warm absorber" gas at different resolutions. Note that many lines do not appear to be saturated at low resolution.

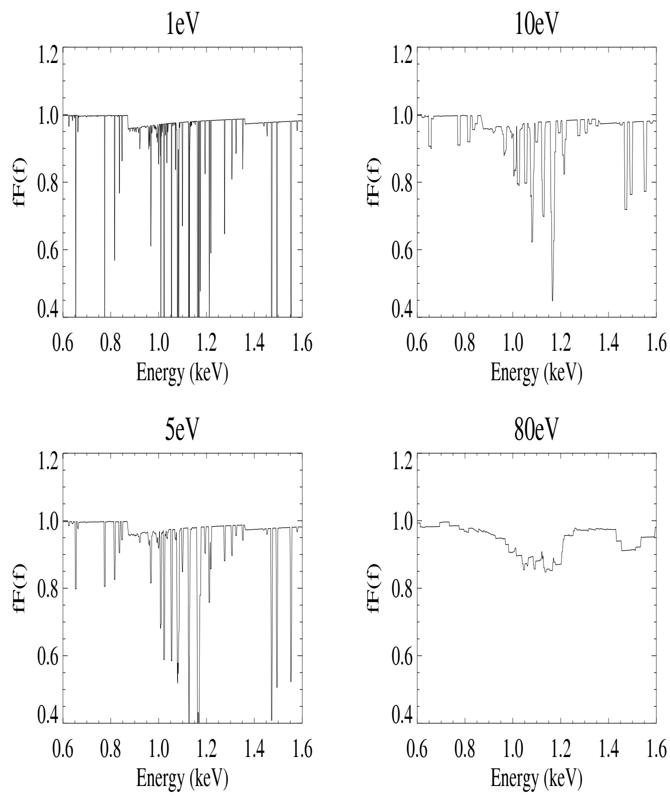


Figure 5: An expanded version of the AGN spectrum in the low energy range. Note that many lines do not appear to be saturated at low resolution. At 1 keV a resolution of at least 1,000 is required to determine whether lines are saturated.

What resolution is needed to diagnose the plasma?

- In the soft part of the spectrum (0.6–1.6 keV) the spectrum is very rich and many lines are saturated. A resolution of 1 eV ($R = E/\Delta E \approx 1,000$) is needed to separate the lines and measure the central line depths (essential for determining the column depths of saturated lines). (See Figure 4.)
- In the hard part of the spectrum (8.0–10.0 keV) the lines are widely separated and weak. A resolution of 10 eV ($R \approx 1,000$) is probably sufficient to measure the line column densities. (See Figure 5.)
- The 6.6 keV iron feature is saturated. To measure its column density accurately will require a resolution better than 5 eV ($R > 1,300$).

What spectral resolution is needed to measure electron densities?

- The Ne IX triplet: 13.45 Å (r), 13.55 Å (i), 13.70 Å (f)
- The i/f ratio measures electron densities in the range 10^{11}–10^{13} cm^{-3}. (See Figures 6 and 7.)
- Simulations based on the APEC v. 1.2 code assuming the DEM of σ^2 CrB (an RS CVn binary system).
- At R = 300 it is not possible to measure n_e at any density even with infinite S/N.
- At R = 1,000 it is difficult to measure n_e at 10^{11} – 10^{12} cm^{-3}, but not at higher n_e even with very high S/N.
- At R = 3,000 one can accurately measure n_e.

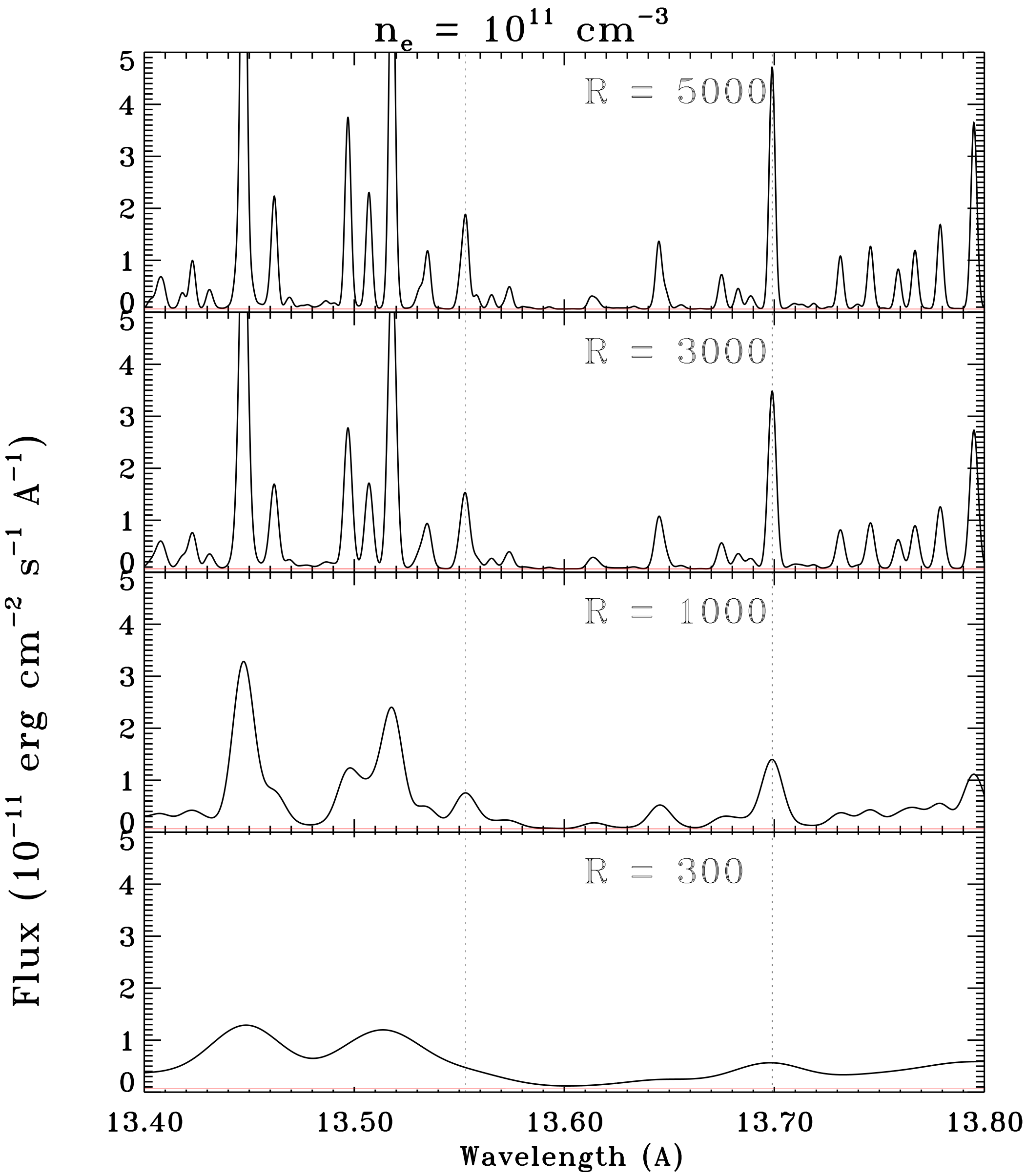


Figure 6: Computed spectrum of a stellar corona using the emission measure distribution for σ^2 CrB and an assumed electron density of 10^{11} cm^{-3}. The vertical dotted lines are for the intersystem (13.55 Å) and forbidden (13.70 Å) lines of Ne IX.

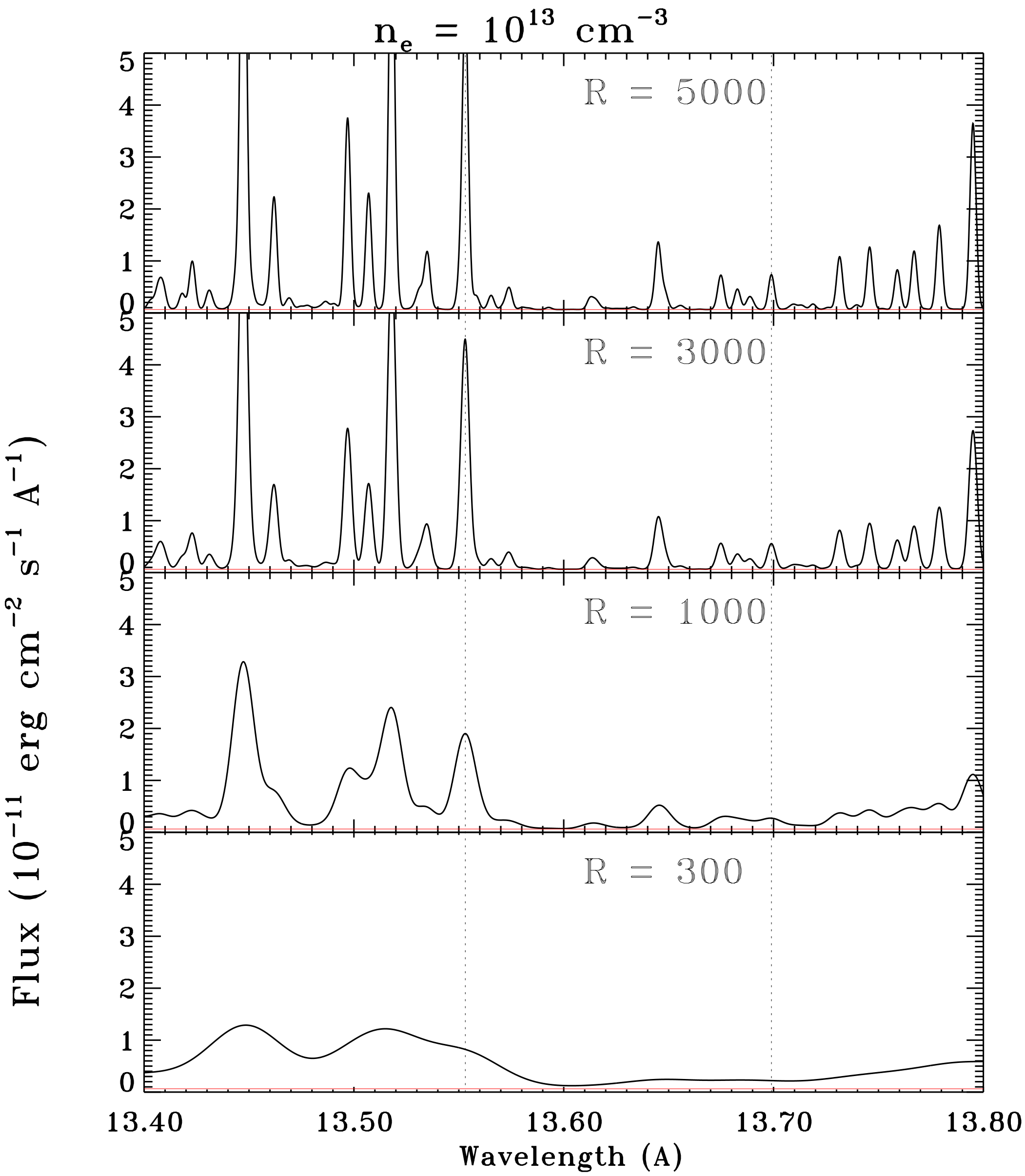


Figure 7: Same as Figure 6 except for an electron density of 10^{11} cm^{-3}.

What spectral resolution is needed to measure the continuum and to separate spectral lines?

- Simulation of the 11–12 Å spectrum of σ^2 CrB using its DEM and the APEC v. 1.2 code. (See Figure 8.)
- At R = 300 one cannot measure the continuum or separate spectral lines.
- At R = 1,000 and very high S/N one can measure the continuum and measure the flux of isolated lines.
- At R = 3,000 One can accurately measure the continuum and the fluxes of most spectral lines even with moderate S/N.

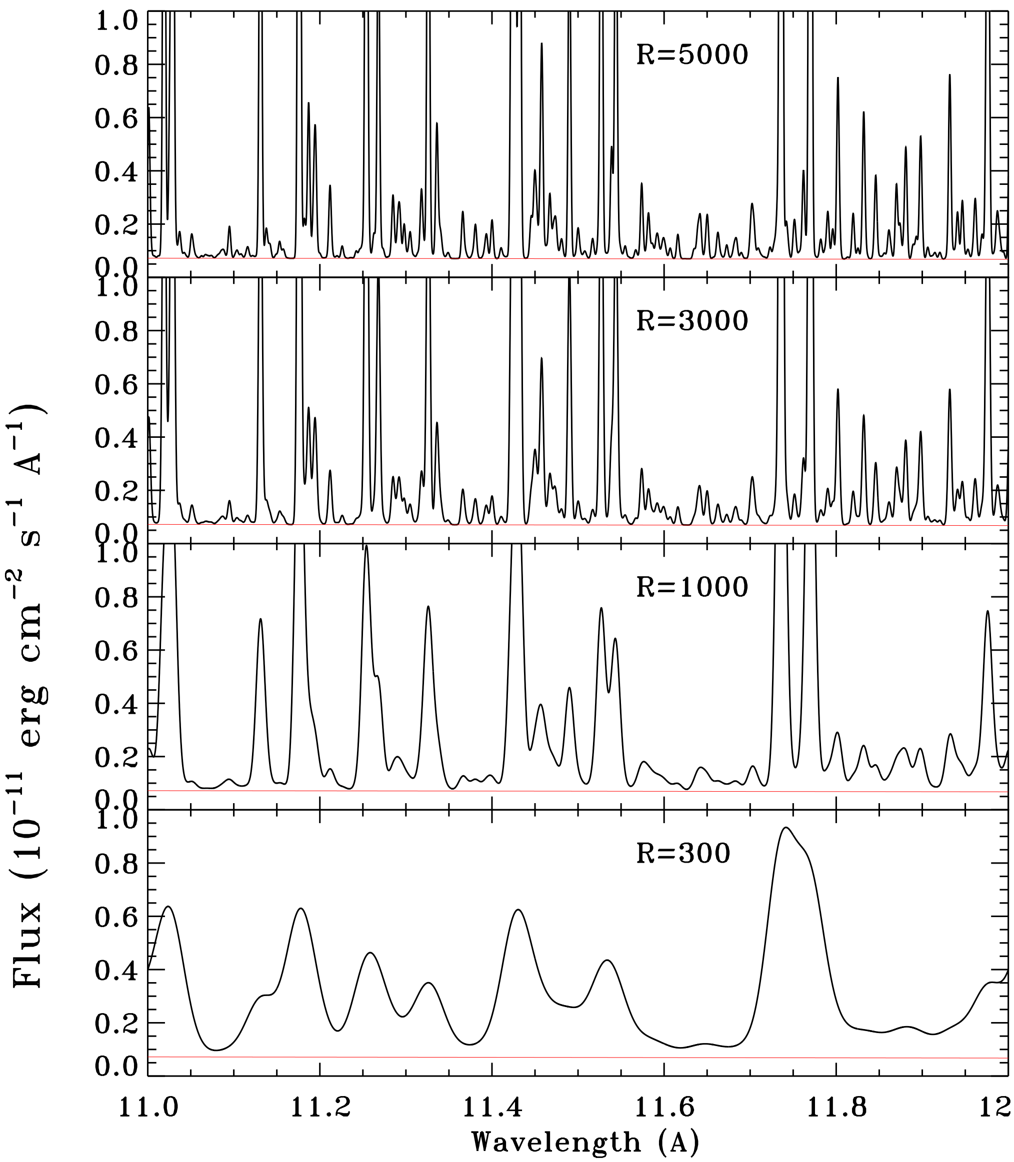


Figure 8: Simulation of the 11–12 Å spectrum of σ^2 CrB at different resolutions. The horizontal line just above zero flux is the computed continuum. At a resolution of 1,000 it is difficult to measure the continuum flux even with very high S/N. An accurate measurement of the continuum is essential for determining metal abundances relative to hydrogen.

What spectral resolution is needed to measure line widths, line asymmetries, and the continuum?

- Simulation for the Ne IX 13.45 Å line in AR Lac. Con-X should detect 300 counts in the line in 300 seconds. Intrinsic line width about 80 km/s.
- To measure the line width need R $\geq 3,000$.
- To identify two lines split by 180 km/s need R $\geq 3,000$.
- To identify a line asymmetry (a component 25% of the main peak separated by 90 km/s) need R $\geq 3,000$.
- To measure the continuum the resolution must be at least as good as the minimum line separation, R = 3,000–5,000.

What resolution is needed to measure thermal line widths?

For lines with 300 counts, the minimum resolution needed is $R = 1400\sqrt{(m/T_6)}$.

Ion	At. Weight	$\log T_{ion}$	Resolution
O VII	16	6.3	4,000
O VIII	16	6.7	2,500
Ne IX	20	6.6	3,200
Ne X	20	6.9	2,200
Mg XII	24	7.2	1,700
Si XIV	28	7.4	1,500
Fe XVII	56	6.7	4,700
Fe XXV	56	7.8	1,300

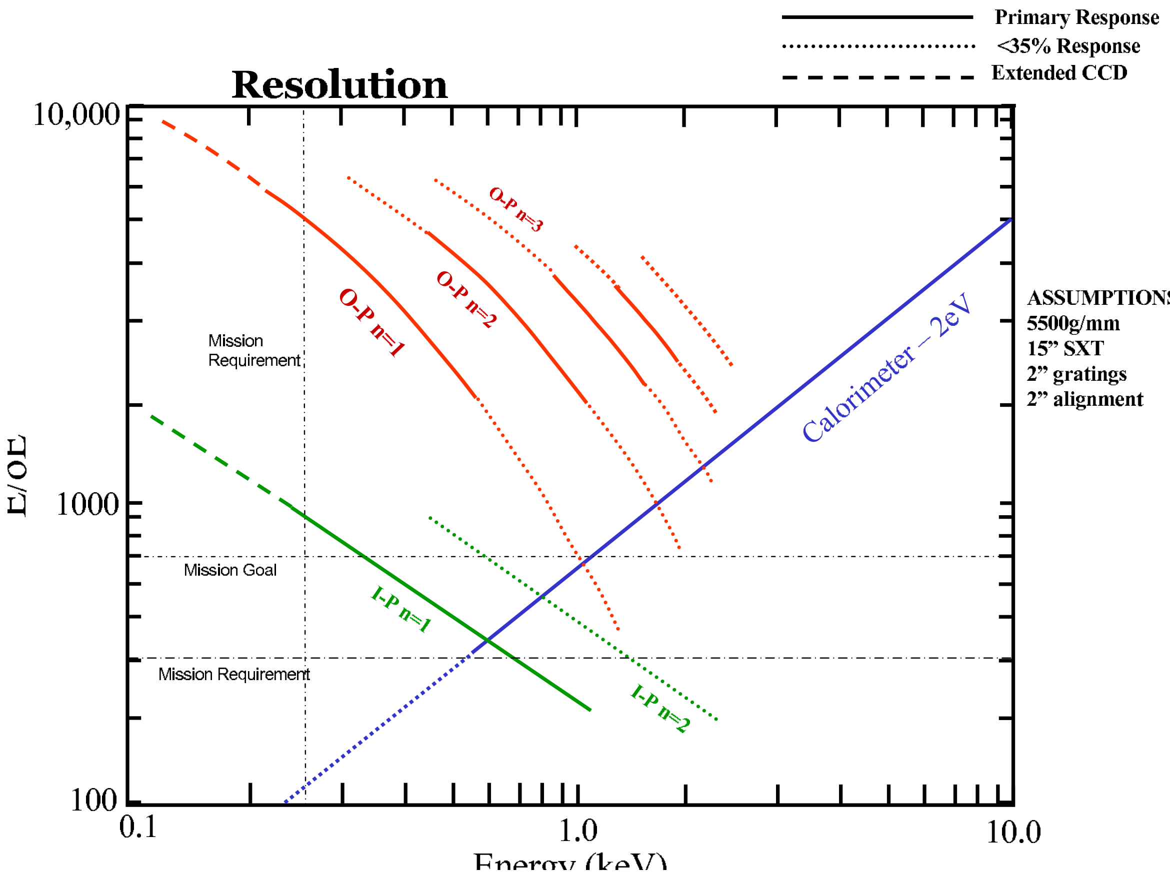
5 What spectral resolution is needed for Con-X?

Requirement: R = 1,500 (Will accomplish many of the science objectives)

Goal: R = 4,500 (Will accomplish all of the science objectives).

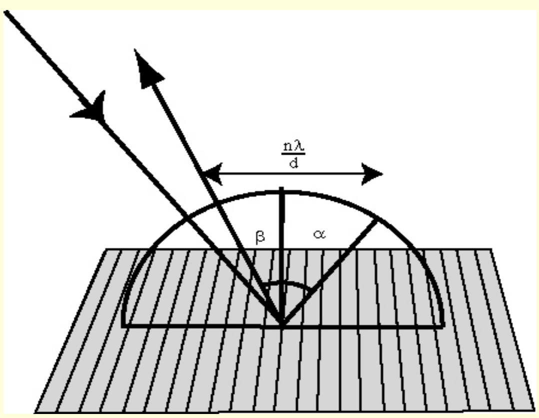
Is this feasible? Web Cash is developing off-plane radial groove reflection grating designs to accomplish the R = 4,500 goal.

The next 4 figures are taken from a presentation made by Webster Cash in September 19, 2002. They show that high spectral resolution with high throughput is possible with the off-plane radial groove reflection grating architecture. The Con-X project is presently funding this development work, and we look forward to a successful high resolution mission in the not too distant future.


Primary Response
<35% Response
Extended CCD
Resolution
10,000
1000
100
E/δE
0.1
1.0
10.0
Energy (keV)
O-P n=1
O-P n=2
O-P n=3
I-P n=1
I-P n=2
Calorimeter – 2eV
Mission Requirement
Mission Goal
Mission Requirement
ASSUMPTIONS
5500g/mm
15" SXT
2" gratings
2" alignment

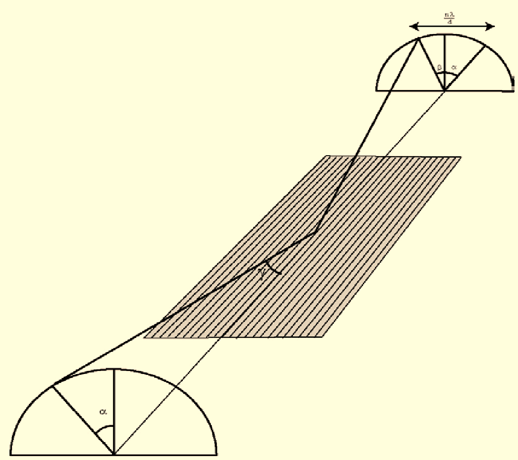
In-plane Mount

$$\sin\alpha + \sin\beta = \frac{n\lambda}{d}$$



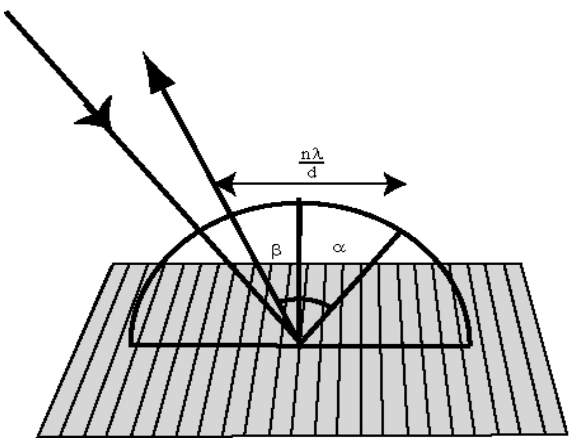
Off-plane Mount

$$\sin\alpha + \sin\beta = \frac{n\lambda}{d\sin\gamma}$$



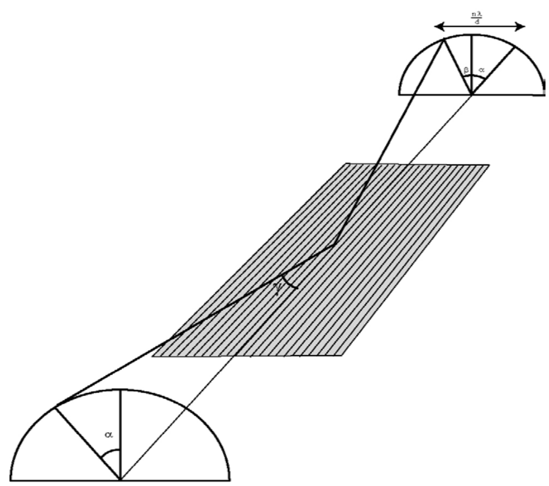
In-plane Mount

$$\sin\alpha + \sin\beta = \frac{n\lambda}{d}$$

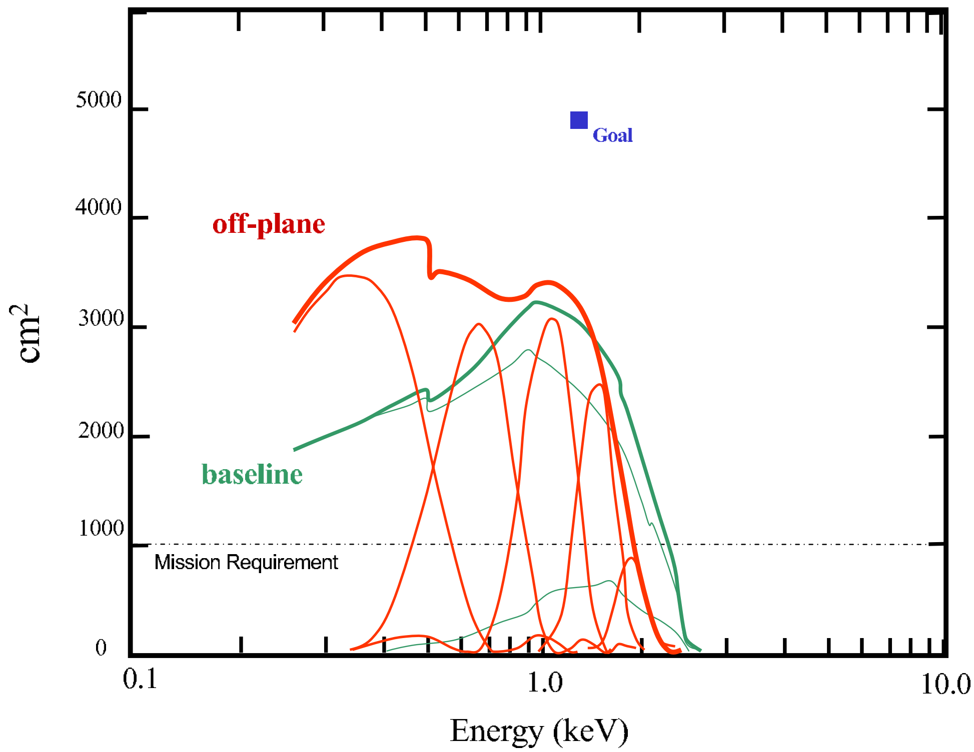


Off-plane Mount

$$\sin\alpha + \sin\beta = \frac{n\lambda}{d\sin\gamma}$$



Effective Area



ASSUMPTIONS:

Coverage 40% of outer envelop

Off-Plane Groove Efficiency 80% of theoretical

85% Structure Transmission

CCD thin Al filter only